วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา ปีที่ 17 ฉบับที่ 2, ธันวาคม 2560

Journal of Sports Science and Technology Volume 17, No. 2, December 2017

THE ACUTE EFFECTS OF *RHODIOLA CRENULATA* ON SUBMAXIMAL EXHAUSTIVE PERFORMANCE UNDER HEAT STRESS

Saiphon KONGKUM, Suthasinee KONGTHONGSUNG*, Waree WIDJAJA, Rungchai CHAUNCHAIYAKUL

College of Sports Science and Technology, Mahidol University, Nakhon Pathom, Thailand 73170

ABSTRACT

Introduction: *Rhodiola crenulata* is a traditional Chinese herb, which is widely used for health promotion in the Tibet and Himalayan areas. *Rhodiola* extract contains salidroside, a biologically active compound, which potentially has ergogenic and adaptogenic benefits, to decrease inflammation and improve exercise tolerance. **Purpose**: This study aimed to investigate the effects of *Rhodiola crenulata* on submaximal exercise performance and physiological responses under heat stress (~35.5±0.16°C and relative humidity of ~58.6±2.34%). **Methods**: Thirteen healthy males (aged, 20.9±1.7 yrs; body mass, 67.2±7.8 kg; height, 172.7±5.4 cm; peak oxygen consumption $\dot{V}O_{2peak}$, 49.0±3.4 $mL.kg^{-1}.min^{-1}$) volunteered to participate in this randomized, double-blind, crossover study. Participants completed three exercise sessions. On day 1, $\dot{V}O_{2peak}$ was determined and used for establishing a workload of 70-75% $\dot{V}O_2$peak in the subsequent day 2 and 3. On day 2 and 3, participants were randomized to receive a single 500 milligrams dose of either *Rhodiola crenulata* (RC) or Placebo (PL) an hour before completing submaximal exhaustive treadmill running at 70-75% $\dot{V}O_{2peak}$ under heat stress. Cardiac, respiratory, metabolic, and thermoregulatory responses, and ratings of perceived exertion, were measured before and during the test. Time to exhaustion (TTE), speed and distance covered were recorded at the end of testing. **Results**: Seven participants (out of 13) had a longer TTE and covered a greater distance when consuming RC extract although there was no significant difference between conditions (TTE: PL, 30.2±3.7 min; RC, 29.8±2.0 min., and distance covered: PL, 4.7±0.6 km; RC, 4.9±0.4 km, respectively). Physiological responses: cardiac, respiratory, metabolic and thermoregulatory functions were all similar at rest and during submaximal exercise between conditions (p>0.05). The perception of thermal sensation and discomfort were similar at rest and exhaustion. However, these subjective variables were rated significantly different in the 9^{th} min (PL, 2.8±0.2; RC, 1.8±0.2, and PL, -2.5±0.2; RC, 1.6±0.2, p<0.05, respectively). **Conclusion**: Our finding suggests that a 500 mg acute single dose of RC has no additive beneficial effect on submaximal exhaustive performance compared to a placebo under heat stress.

(Journal of Sports Science and Technology 2017; 17(2): 83-95)

Keywords: *Rhodiola Crenulata* / Supplement / Exercise Performance / Exercise in the heat

***Corresponding author**: Suthasinee Kongthongsung
College of Sports Science and Technology,
Mahidol University, Nakhon Pathom, Thailand. 73170
E-mail: suthasinee.kyo@gmail.com

วารสารวิทยาศาสตร์และเทคโนโลยีการกีฬา ปีที่ 17 ฉบับที่ 2, ธันวาคม 2560

Journal of Sports Science and Technology Volume 17, No. 2, December 2017

ผลแบบฉับพลันของ *Rhodiola crenulata* ต่อสมรรถภาพการออกกำลังกายในระดับต่ำกว่าการใช้ออกซิเจนสูงสุดภายใต้สภาวะความเครียดจากความร้อน

สายฝน กองคำ, สุธาสินี คงทองสังข์, วารี วิดจายา และ รุ่งชัย ชวนไชยะกุล

วิทยาลัยวิทยาศาสตร์และเทคโนโลยีการกีฬา มหาวิทยาลัยมหิดล อ.พุทธมณฑล จ.นครปฐม ประเทศไทย 73170

บทคัดย่อ

บทนำ *Rhodiola crenulata* เป็นสมุนไพรจีนถูกใช้ในการบำรุงสุขภาพในประเทศทิเบตและแถบหิมาลัย *Rhodiola crenulata* (RC) มีสารประกอบทางเคมีที่สำคัญคือ Salidroside ซึ่งมีคุณสมบัติช่วยเพิ่มสมรรถภาพทางกายและการปรับตัว ช่วยลดการอักเสบ ลดอาการเหนื่อยล้า และเพิ่มสมรรถภาพการออกกำลังกาย **วัตถุประสงค์การวิจัย** เพื่อศึกษาผลของ RC ต่อสมรรถภาพการออกกำลังกายในระดับต่ำกว่าการใช้ออกซิเจนสูงสุดและการตอบสนองทางสรีรวิทยาภายใต้สภาวะความเครียดจากความร้อน (ที่อุณหภูมิ 35.5±0.2 องศาเซลเซียสและความชื้นสัมพัทธ์ 58.6±2.3 เปอร์เซ็นต์) **วิธีการวิจัย** อาสาสมัครเพศชายสุขภาพดีจำนวน 13 คน (อายุ 20.9±1.7 ปี น้ำหนัก 67.2±7.8กิโลกรัม ส่วนสูง 172.7±5.4 เซนติเมตร และอัตราการใช้ออกซิเจนสูงสุด ($\dot{V}O_{2peak}$) 49.0±3.4 มิลลิลิตรต่อกิโลกรัมต่อนาที) เข้าร่วมวิจัยโดยการสุ่มและไขว้กลุ่มจากผู้ช่วยวิจัย และทำการทดสอบสมรรถภาพทางกายทั้งหมด 3 ครั้ง ในวันที่ 1 จะได้รับการทดสอบ $\dot{V}O_{2peak}$ เพื่อใช้คำนวณความหนักที่ 70-75% ของ $\dot{V}O_{2peak}$ สำหรับการทดสอบในวันที่ 2 และ 3 ซึ่งในวันที่ 2 และ 3 ผู้เข้าร่วมวิจัยได้รับการสุ่มการได้สารสกัด RC ในปริมาณ 500 มิลลิกรัม หรือสารหลอก (PL) โดยใช้เม็ดแป้ง 1 ชั่วโมงก่อนการทดสอบสมรรถภาพทางกายโดยการวิ่งด้วยความเร็วที่สอดคล้องกับการใช้ออกซิเจนสูงสุดที่ 70-75% ของ $\dot{V}O_{2peak}$ จนกระทั่งไม่สามารถวิ่งต่อไปได้ ตลอดการทดสอบทำการวัดการตอบสนองทางสรีรวิทยา ได้แก่ การทำงานของระบบหัวใจ ระบบหายใจ ระบบเผาผลาญพลังงาน และระบบรักษาอุณหภูมิกาย ตลอดจนการประเมินความรู้สึกเหนื่อยและการรับรู้ความร้อน เมื่อสิ้นสุดการทดลองทำการบันทึกระยะเวลาในการวิ่ง ระยะทางทั้งหมด และความเร็วเฉลี่ย **ผลการวิจัย** ผู้เข้าร่วมวิจัย 7 คน (จาก 13 คน) เมื่อได้รับสารสกัดจาก RC ไม่พบความแตกต่างอย่างมีนัยสำคัญทางสถิติระหว่างกลุ่มในการวิ่ง (PL, 30.2±3.7 นาที; RC, 29.8±2.0 นาที) และระยะทาง (PL, 4.7±0.6 กิโลเมตร; RC, 4.9±0.4 กิโลเมตร) การตอบสนองทางสรีรวิทยา เช่น ทำงานของระบบหัวใจ การหายใจ การเผาผลาญพลังงาน และการรักษาอุณหภูมิกายมีการตอบสนองไปในทิศทางเดียวกันทั้งในขณะพักและระหว่างการออกกำลังกายในระดับต่ำกว่าการใช้ออกซิเจนสูงสุดใน PL เปรียบเทียบกับ RC (p>0.05). การรับรู้ต่อความรู้สึกร้อนและความไม่สบายจากความร้อนพบว่ามีการตอบสนองไปในทิศทางเดียวกันทั้งในขณะพักและขณะที่หมดแรงจนไม่สามารถวิ่งต่อไปได้ อย่างไรก็ตามพบว่ามีความแตกต่างกันอย่างมีนัยสำคัญในนาทีที่ 9 (PL, 2.8±0.2; RC, 1.8±0.2, และ PL, -2.5±0.2; RC, 1.6±0.2, p<0.05, ตามลำดับ) **สรุปผลการวิจัย** ผลแบบฉับพลันของการได้รับ RC 500 มิลลิกรัมไม่มีผลต่อการเพิ่มสมรรถภาพการออกกำลังกายในระดับต่ำกว่าการใช้ออกซิเจนสูงสุด เมื่อเปรียบเทียบกับสารหลอกภายใต้สภาวะความเครียดจากความร้อน

(Journal of Sports Science and Technology 2017; 17(2): 83-95)

คำสำคัญ: *Rhodiola Crenulata* / อาหารเสริม / สมรรถภาพการออกกำลังกาย / การออกกำลังกายภายใต้สภาวะเครียดจากความร้อน

INTRODUCTION

Prolonged endurance exercise in hot environments may lead to hyperthermia, an increased cardiovascular strain and metabolic disturbance, and impaired central nervous system activation, which may induce excessive oxidative damage and impair exercise capability.[1-3] An elevated aerobic exercise metabolism may increase the production of reactive oxygen species, lower cellular function and pose a stress related health risk.[4] Anecdotal evidences, suggested that dietary herbal supplements, such as *Ginseng*, *Cordyceps*, *Rhodiola* and *Ginkgo* have been become popular and widely used supplements to promote health, prevent diseases and enhance whole body well-being both physical and mental stress.[5, 6] More recently, herbal supplements have gained a greater attention due to their potential ergogenic performance effects.

Rhodiola crenulata (RC) is a traditional Chinese herb, which has been used in Tibetan and Himalayan areas since ancient times. Salidroside, the major biologically active compound of *Rhodiola* extract, is thought to be responsible for its antioxidant[7-9], anti-fatigue[10-13], anti-inflammation[14-16] and mental alertness properties[17, 18], both in healthy and patient populations. Moreover, salidroside is known to be a phytoadaptogen, taken by military and aerospace personnel, to help the body adapt and resist physical, chemical and environmental stresses.[19] Its effect is dose-dependent, with a daily dosage of 500 mg of *Rhodiola* extract typically prescribed (range between 100-972 mg).[7, 9, 20, 21] It is also used to improve athletic performance, shortening recovery time after exercise and mental tasks.[20, 22, 23] Recently, the combined chronic effects of RC plus *Cordyceps* extract following altitude training has been shown to prolong exhaustive run time and promote parasympathetic activity in long distance track and field athletes.[5] The combined effects of RC plus *Ginkgo* extract on endurance performance has been shown to increase oxygen consumption, with the unchanged levels of serum cortisol and testosterone and cortisol ratios indicating protection against fatigue in healthy males.[6] However, it remains unclear whether these findings are related to supplementation of RC or others substances *per se*, or in combination. It is purported that *Rhodiola* extract improves exercise capacity via activation of the energy processes of ATP synthesis/resynthesis and stimulation of the recovery process after exhaustive exercise.[24] Nonetheless, it has been shown that *Rhodiola* ingestion does not improve ATP turnover during or immediately after exercise in resistance trained males[25] or attenuate the decrease in post-exercise muscle function, or increase in muscle damage, after a marathon.[26] Several studies have focused on the effects that *Rhodiola* extract may have on antioxidant activity.[7-9] In a rodent model, *Rhodiola* extract increased exercise tolerance and improved antioxidant defense mechanisms by decreasing exhaustive swimming-enhanced oxidative stress.[10, 11] In human studies, The acute effects of *Rhodiola* extract on aerobic performance, muscle strength, speed of limb movement, reaction time and attention, has been shown to significantly increase time to exhaustion, and O_2 and CO_2 kinetics, in both physically active males and females.[12] In contrast, these parameters were not changed with chronic supplementation.[12] Furthermore, the acute effect of *Rhodiola* extract on 6 mile-time trial performance has been shown to increase perceived exertion, mood and cognitive function in recreationally active women. The decreased heart rate response to submaximal exercise suggested that endurance exercise performance was improved by decreasing the perception of effort.[13] In other studies, it has been reported that *Rhodiola* extract improves student's psychological function during examination periods by reducing mental fatigue and increasing work capacity.[17, 18] It is proposed that *Rhodiola* extract may have bi-directional functions for central nervous system and endocrine system accommodation, maintaining the body in a well-balanced condition.[27, 28]

Previous studies demonstrate that a single acute ingestion RC extract may improve endurance capacity and resistance to fatigue. To our knowledge, there is no study that has explored the acute effects of a single dose of RC extract on submaximal exercise performance under heat stress. Therefore, the aim of the present study was to examine the acute effect of RC extract on submaximal exercise performance and physiological responses in a hot and humid environment. We hypothesized that RC would increase submaximal exercise performance under heat stress.

MATERIALS AND METHODS

Thirteen healthy males (aged, 20.9±1.7 years; body mass, 67.2±7.8 kg; height, 172.7±5.4 centimeters; and $\dot{V}O_{2peak}$, 49.0±3.4 $mL.kg^{-1}.min^{-1}$) volunteered to participate in this study. Their health history and habitual physical activity levels were recorded using questionnaires, and the signed Informed consents were provided. This study was approved by the Ethical Committee of Mahidol University Institutional Review Board. The experiment was conducted under a controlled thermal temperature (~35-40 ºC) and relative humidity (~50-60%) at the same time of day to avoid diurnal variation. The study was administered using a randomized, double-blind, crossover design. Each participant was asked to attend the laboratory on three occasions. On day 1, after familiarization of study procedures, a Modified Bruce protocol was performed to determine each participant's peak oxygen consumption ($\dot{V}O_{2peak}$). This test was performed in order to establish the relative exercise intensity on the subsequent day 2 and 3. The test was terminated following these criterias: HR increase above 85% of age-predicted maximal HR (220 - age), a plateau of $\dot{V}O_2$ with an increasing workload, or a $\dot{V}O_2$ increase of less than 2 $mL.kg^{-1}.min^{-1}$after 2 min, an RER >1.2 and/or volitional exhaustion. On day 2 and 3, a submaximal performance run, corresponding to 70-75%$\dot{V}O_{2peak}$, was performed by adjusting the treadmill speed. Each participant was randomized to ingest either a 500 mg per capsule of *Rhodiola crenulata* (RC) or Placebo (PL) (TCM Biomedical International Corp., Taiwan), separated by a minimum of 7 days to ensure adequate recovery and wash out the effect of the first supplement. Supplements were ingested 1 hour prior to the start of running until exhaustion. These criterion were used to terminate the exercise protocol: 1) HR increased above 85% of age-predicted maximal HR (220 - age), 2) core temperature increased above 39.0 °C, 3) unable to maintain the instructed intensity on the treadmill and

4) volitional exhaustion. Cardiac functions: heart rate (HR), stroke volume (SV), and cardiac output (CO), were monitored using a non-invasive hemodynamic device (Physioflow©, USA). Metabolic and respiratory functions: oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), respiratory rate (RR), tidal volume (V_T), and minute ventilation ($\dot{V}_E$) were monitored using the telemetry gas analyzer (Oxycon Mobile©, USA). Thermoregulatory responses were assessed by measuring core body temperature (T_{core}) using a core body monitoring data recorder and ingestible sensor (FL 34221-4802 HQInc©, USA) and mean skin temperature ($\bar{T}_{sk}$), monitored using skin thermistors (New YSI 400 series, Japan). $\bar{T}_{sk}$ was calculated using the following equation[29];

$$\bar{T}_{sk} = 0.15(T_{chest}) + 0.15(T_{back}) + 0.3(T_{forearm}) + 0.2\,(T_{thigh} + T_{calf})$$

Skin blood perfusion was measured at rest under thermal conditions and immediately after exercise using a laser Doppler device (MoorVMA –LDF2, UK). The percentage changes (%changes) from rest were calculated using the following equation;

$$\left[\frac{\text{immediately after exercise value} - \text{resting value}}{\text{resting value}}\right] \times 100$$

Subjective rating of perceived exertion (RPE) under heat stress was assessed using the 6-20 Borg's ratings scale (Gunnar Borg, 1985). The participant's perceived thermal sensation (TSS) and discomfort (TDS) was recorded using scales (Berglund, 1998). Cardiac function, metabolic and thermoregulatory responses and subjective measurements were recorded at rest and throughout exercise. Nude body weight was measured pre- and post-exercise using body weight scales (Sartorius, Germany) and %changes in body weight was calculated.

Time to exhaustion (TTE), average speed, and distance covered were recorded as an indicator of endurance performance. Resting heart rate (RHR), resting blood pressure (RBP) and urine specific gravity (USG) were measured prior to the start of each exercise session to ensure normal hydration status and minimize the risk of heat illness. Food intake and water were recorded to control the same caloric intake (24 h food diary). Prior to the experimental day, the participant was instructed to adhere to the following physical preparation: 1) consume similar meals the day before the testing date, 2) drink an appropriate amount of water ~6-8 cups per day 3) refrain from strenuous exercise for 24 hours, 4) refrain from consumption of alcohol for 24 hours and caffeine for 12 hours, and 5) appropriate sleep for 6-8 hours per day.

STATISTICAL ANALYSIS

The data are presented as mean and standard error of mean (Mean±SEM). The normal distribution of data was determined using a Shapiro-Wilk test. The difference in TTE, distance covered, average speed, %changes in skin blood perfusion and %changes in body weight between conditions were assessed using a paired T-Test. Physiological responses, including HR, SV, CO, $\dot{V}O_2$, $\dot{V}CO_2$, RR, V_T, $\dot{V}_E$, $\bar{T}_{sk}$, T_{core}, and RPE were all analyzed using a two-way repeated measures ANOVA with main effects of condition, time and interaction. If a significant main effect were found for ANOVA measurements, a *Post-hoc* Bonferroni multiple comparison was applied. Statistical significance was set at p<0.05.

A non-parametric test was applied to RER, TSS and TDS since the data was not normally distributed. A Friedman test was used to compare the effects of condition and time. When a significant effect was found, the Wilcoxon signed rank test was used and pairwise comparisons and Bonferroni corrections were applied. The significance level was set at p<0.025. All statistical analysis was performed using SPSS software version 20.

RESULTS

Submaximal exhaustive exercise performance

Average speed corresponding to 70-75% $\dot{V}O_{2peak}$ was not different between conditions (PL; 9.4±0.2 km/h and RC; 9.6±0.3 km/h, p=0.13). There was no difference in TTE between conditions (PL; 30.2±3.7 min and RC; 29.7±2.0 min, p=0.88; Figure 1). In addition, the distance covered was similar between conditions (PL; 4.7±0.6 km and RC; 4.9±0.4 km, p=0.63; Figure 1). However, 7 of the 13 participants improved their TTE and distance covered in the RC compared to PL condition.

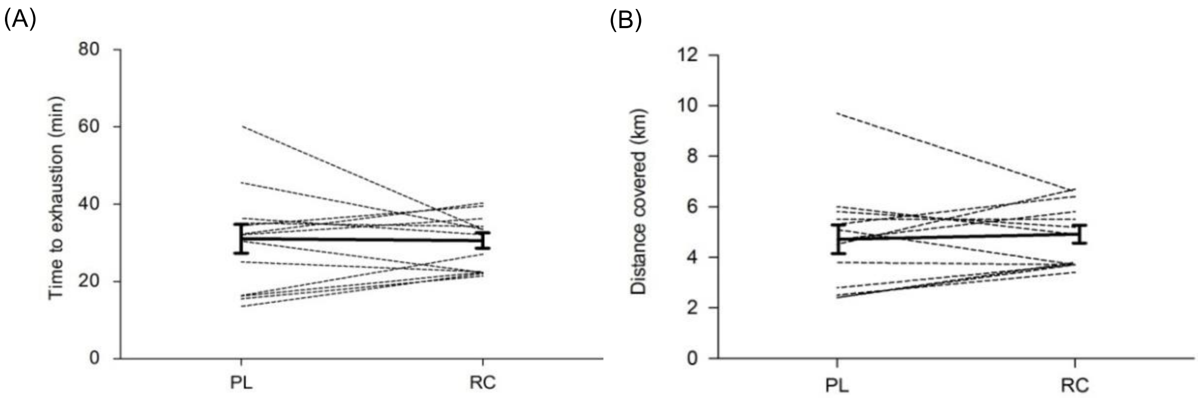

Figure 1 (A) TTE and (B) distance covered in the PL and RC conditions. Data are presented as individual values (dashed line) and the mean values (solid line) ± SEM *(error bars)*.

Cardiac functions

Resting HR (PL; 67.9±2.7 and RC; 63.4±2.9 bpm), SV (PL; 83.1±3.3 and RC; 83.6±3.3 mL) and CO (PL; 5.5±0.2 and RC, 5.4±0.2 L/min) was similar between conditions (p>0.05). HR, SV and CO were significantly increased during submaximal exercise. Average HR (PL; 165.6±1.8 and RC; 164.8±2.7 bpm), SV (PL; 123±6.9 and RC; 130.4±5.0 mL), and CO (PL; 19.9±0.7 and RC; 21.5±0.8 L/min) were also similar between the PL and RC conditions, respectively. Each cardiac variable generally increased from rest during submaximal exercise (p<0.001), however no condition or interaction effect were observed.

Metabolic and respiratory functions

Resting $\dot{V}O_2$(PL; 4.9±0.3 and 4.7±0.3 $mL.kg^{-1}.min^{-1}$), $\dot{V}CO_2$(PL; 4.1±0.3 and RC;4.2±0.3 $mL.kg^{-1}.min^{-1}$, RER (0.8±0.01 and 0.9±0.01), RR (PL; 18.7±1.1 and RC; 18.0±1.1 bpm), V_T (PL; 0.6±0.03 and RC; 0.6±0.03 L) and $\dot{V}_E$ (PL; 10.7±0.6 and RC; 10.6±0.6 L/min) were all similar between PL and RC conditions, respectively (p>0.05). $\dot{V}O_2$ was controlled corresponding to 70-75% $\dot{V}O_{2peak}$ until exhaustion (PL; 36.5±0.1 and RC; 36.3±0.2 $mL.kg^{-1}.min^{-1}$, p>0.05). Average $\dot{V}CO_2$ (PL; 37.0±0.4 and RC; 37.6±0.4 $mL.kg^{-1}.min^{-1}$), RER (PL; 1.02±0.01 and RC; 1.03±0.01), RR (PL; 48.8±2.6 and RC; 50.1±2.4 bpm), V_T (1.6±0.1 and 1.6±0.1 L) and $\dot{V}_E$ (PL; 77.6±4.1 and RC; 77.3±3.1 L/min) were also not different between PL and RC conditions during submaximal exercise. All parameters increased from rest during submaximal exercise (p<0.001) but there were no condition or interaction effects.

Thermoregulatory responses.

Resting T_{core} (PL; 36.9±2.8°C and RC; 36.9±2.8°C, p=0.98) and $\bar{T}_{sk}$ (PL; 34.4±0.1°C and RC; 34.5±0.2°C, p=0.75) were similar between conditions. Whilst T_{core} and $\bar{T}_{sk}$, significantly increased from rest during exercise in both conditions ($p<0.05$), T_{core} (PL; 39.2±0.1°C and RC; 39.1±0.1°C, p=0.71) and $\bar{T}_{sk}$ (PL; 35.7±0.1°C and RC; 35.8±0.1°C, (p=0.66) were not different between conditions at exhaustion. There were no condition or interaction effects for either T_{core} or $\bar{T}_{sk}$ (Figure 2).

In addition, Percent changes of skin blood perfusion (PL; 686.4±72.4 and RC; 667.5±89.4%) in PL were also similar between conditions (p=0.82). Percent changes of body mass were not different between conditions (PL; 2.0±0.2 and RC; 1.8±0.2%, p=0.45).

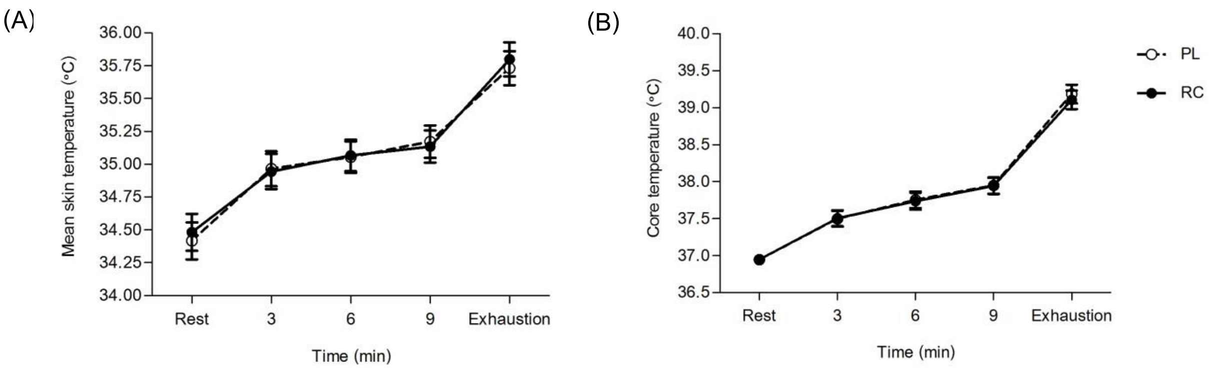

Figure 2 (A) $\bar{T}_{sk}$ and (B) T_{core} measured at rest and during submaximal exhaustive running under heat stress after PL (*white circles*) and RC (*black circles*) supplementation. Data are presented as the Mean±SEM (*error bars*).

Subjective measurements

Resting RPE (PL; 6.0±0.0 and RC; 6.0±0.0), TSS (PL; 0.7±0.1 and RC; 0.4±0.1) and TDS (PL; -0.3±0.1 and RC; 0.1±0.1) were similar (*p*>0.05) in the PL and RC conditions, respectively. At exhaustion, RPE was significantly increased from rest in both conditions (PL; 19.8±0.2 and RC; 19.5±0.2, *p*>0.05, Figure 3). TSS also significantly increased at exhaustion compared to rest in both conditions (PL; 3.5±0.2 and RC; 3.2±0.3 *p*>0.05, Figure 3). However, TDS was significantly reduced below resting values (PL; -3.4±0.2 and RC; -3.1±0.3 *p*<0.05) in both the PL and RC conditions. TSS and TDS were observed to be significantly different between PL and RC conditions at the 9th min of exercise (Figure 3).

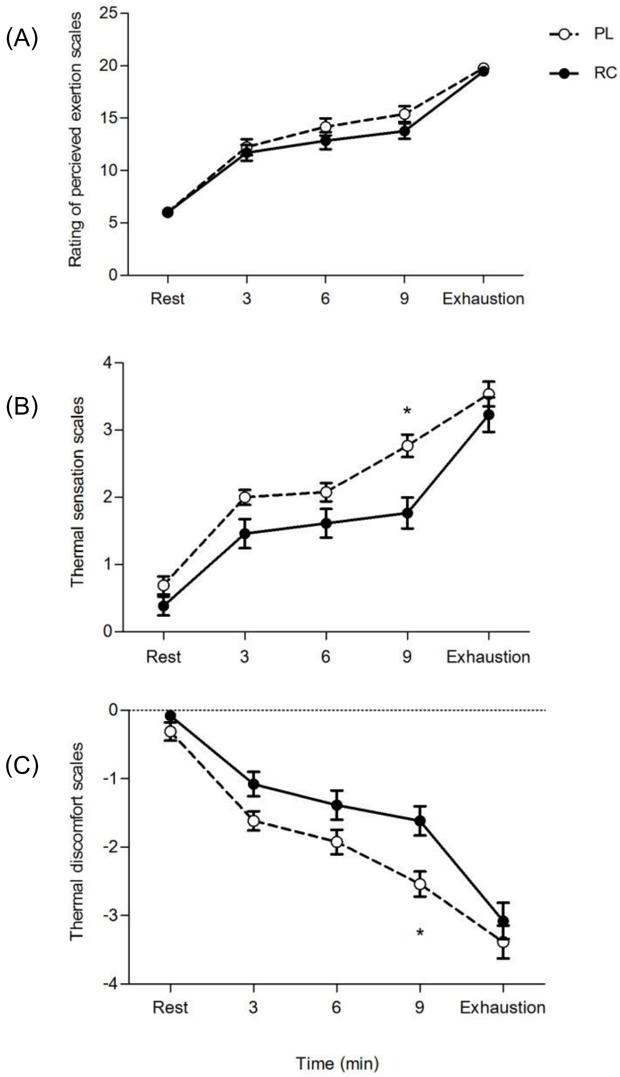

Figure 3 (A) RPE, (B) TSS and (C) TDS assessed during submaximal exhaustive running under heat stress after PL (*white circles*) and RC (*black circles*) supplementation. Data are presented as the Mean±SEM (*error bars*).

DISCUSSION

This is the first study to investigate the effects of an acute single dose of RC ingestion on submaximal exhaustive running performance under heat stress. The results showed that a single dose of RC ingestion has no additive benefit effect on submaximal exhaustive exercise over a placebo under heat stress, however 54% of the participants in the RC condition, prolonged their running time to exhaustion and covered a greater total distance.

In the present study, indicators of endurance performance (TTE and distance covered) were similar between RC and PL conditions in a hot and humid environment. Upon exhaustion, heart rate responses increased to 176 bpm, which was equivalent to 99% of age-predicted maximal heart rate and intestinal core body temperature reached approximately ~39ºC. Taken together, these observations confirm that the participants indeed attained volitional exhaustion upon cessation of exercise. These findings are in line with Parkin and colleagues (1999), who conducted submaximal cycling exercise at 70%$\dot{V}O_{2peak}$ in a controlled temperature (~40ºC) and relative humidity (<50%) and reported an average TTE of 30±3 min, heart rate of 181±2 bpm and a core body temperature response of ≤39 ºC. In the present study, the similar physiological responses was recorded at rest and during submaximal exercise between the PL and RC conditions suggests RC had no effect on physical performance. The higher TSS and lower TDS responses in the RC condition reached a significant difference at 9th min, which might suggest an enhanced psychophysiological response after RC ingestion. Recently, it has been reported that *Rhodiola* extract has an influence on perceived exertion during submaximal cycling performance in active males.[13] It is possible that RC ingestion may positively affect subjective sensation, independent of observing a physiological response, on exercise performance during submaximal exhaustive exercise performance under heat stress.[30]

The fatigue experienced during exhaustive exercise in the heat is related to hyperthermia. The encountered stress imposed on the cardiovascular and thermoregulatory systems by heat and dehydration significantly reduce physical and mental performance. The cardiovascular system compensates for heat stress imposed on the body during exercise by redirecting blood flow from the muscle to the skin for the dissipation of heat.[1] The displacement of blood flow and volume to the periphery leads to a reduction in central blood volume and an increase in SV to compensate for the elevation in HR (cardiovascular drift).[31] Furthermore, exercise in the heat causes loss of body fluid and electrolytes via sweating leading to hyperosmolarity and dehydration, which both have detrimental effects on circulation and thermoregulation. These factors interact with an altered muscle metabolism and contribute to the reduction in endurance performance in the heat.[3] However, animal and human studies suggest that the cardiovascular and metabolic alterations in the working muscles are not the underlying factor of fatigue during prolonged exercise in the heat. It is proposed that a high T_{core}, especially high brain temperature is the key limiting factor since a gradual slowing of the electroencephalography (EEG), a marked reduction in the ability to maintain voluntary contraction and increase in perception effort correlate linearly with rising $\bar{T}_{sk}$, T_{core} and HR.[3, 31-33] In this study, 99% of individual maximal heart rate was attained alongside a core temperature increase of ~39 ºC. This was associated with nearly a 2% decrease in body weight and a maximal RPE in both conditions during exercise under heat stress, which suggests the exhaustion status in the participants upon volitional cessation of exercise.

RC extract ingestion contains salidroside, which is an active compound documented as to have antioxidant and adaptogenic properties.[20, 22, 23] It has therefore been suggested to improve endurance performance via antioxidant carrying capacity causing oxidative suppression to sustain mental and work capacity during exhaustive exercise under heat stress. Bock and colleagues (2004), used an acute dose strategy and observed a significant increase in time to exhaustion during an incremental cycle test to exhaustion.[12] Similarly, Noreen and colleagues (2013) reported RC extract to improve endurance capacity during a 6-mile time trial.[13] The combination effect of RC with other supplements such as *cordyceps* or *ginkgo* has also been studied with increases in prolonged exhaustive running time and a reduction fatigue being reported.[5, 6] In contrast with the present study, despite a number of participants being able to prolong their exercise time, there was still no effect between the PL and RC conditions on submaximal exhaustive performance. Therefore, in this study, ingestion of a single dose of RC does not support the evidence to enhance submaximal exercise by a changed antioxidant actions. Nonetheless, the different protocols, *Rhodiola* species extract used, and environmental conditions, may explain why the current findings differ to other studies. For example, a different exercise protocol performed in different environmental temperatures may lead to an altered level of oxidative stress during exercise. Additionally, the oxidative stress accumulated in this study may not have been large enough to benefit from the antioxidant effect of single dose of RC supplement. Alternatively, the single dose of RC ingestion may have been insufficient to induce a positive benefit on performance. Unfortunately, in this study there was no index measure of oxidative stress to confirm these hypotheses. Therefore, more study is required to confirm the ergogenic effect of RC ingestion, both acute and chronic effect of RC extract, during exercise under heat stress.

CONCLUSION

This was the first study to investigate the effects of an acute single dose of RC on submaximal exhaustive performance, physiological responses and subjective measurements. Our results suggest that acute RC ingestion has no benefits on performance or physiological responses under heat stress. Further study is required to examine the long term effect of RC supplementation on submaximal exhaustive performance under heat stress.

REFERENCES

1. Cheung S.S. Heat stress. In: Bahrk M, Evans J, Zalava M, Maurer K, Cohen C.B, Sexton J, editors. Advanced envirnmental exercise physiology. 1st ed. *Illinois* , United States: Human Kinetics; 2010. p. 27-48.
2. Sawka M.N, Young A.J. Physiologic systems and their responses to conditions of heat and cold. In: Farrell P.A, Joyner M.J, Caiozzo V.J, editors. ACSM's advanced exercise physiology. 2nd ed. Philadelphia, United state: Lippincott Williams and Woilkins; 2012. p. 535-53.
3. Maughan R, Shirreffs S, Watson P. Exercise, heat, hydration and the brain. *J Am Coll Nutr*. 2007;26(5):S604-12.
4. Urso M, Clarkson P. Oxidative stress, exercise, and antioxidant supplementation. *Toxicol*. 2003;189(1):41-54.
5. Chen C.Y, Hou C.W, Bernard J.R, Chen C.C. Rhodiola crenulata- and Cordyceps sinensis-based supplement boosts aerobic exercise performance after short-term high altitude training. *High Alt Med Biol*. 2014;15(3):371-9.
6. Zhang Z.J, Tong Y, Zou J, Chen P.J, Yu D.H. Dietary supplement with a combination of Rhodiola crenulata and Ginkgo biloba enhances the endurance performance in healthy volunteers. *Chin. J. Integr. Med.* 2009;14(3):177-83.
7. Lee S.Y, Li M.H, Shi L.S, Chu H, Ho C.W, Chang T.C. Rhodiola crenulata extract alleviates hypoxic pulmonary edema in rats. *Evid Based Complement Alternat Med*. 2017 Aug 18. 2013;2013:ArticleID 718739;doi:10.1155/2013/718739.
8. Stejnborn S.A, Szczesniak L.P, Basta P, Smielecka E.D. The influence of supplementation with Rhodiola rosea L. extract on selected redox parameters in professional rowers. *Int J Sport Nutr Exerc Metab.* 2009;19(2):186-99.
9. Lee S.Y, Shi L.S, Chu H, Li M.H, Ho C.W, Lai F.Y, Huang C.Y, Chang T.C. Rhodiola crenulata and its bioactive components, salidroside and tyrosol, reverse the hypoxia-induced reduction of plasma-membrane-associated Na, K-ATPase expression via inhibition of ROS-AMPK-PKCξ pathway. *Evid Based Complement Alternat Med*. 2017 Aug 18. 2013;2013:Article ID 284150;doi:10.1155/2013/284150
10. Huang S.H, Lee F.T, Kuo T.Y, Yang J.H, Chien C.T. Attenuation of long-term Rhodiola rosea supplementation on exhaustive swimming-evoked oxidative stress in the rat. *Chin J Physiol.* 2009;52(5):316-24.
11. Lee F.T, Kuo T.Y, Liou S.Y, Chien C.T. Chronic Rhodiola rosea extract supplementation enforces exhaustive swimming tolerance. *Am J Chin Med*. 2009;37(3):557-72.

12. Bock D.K, Eijnde B.O, Ramaekers M, Hespel P. Acute Rhodiola rosea intake can improve endurance exercise performance. *Int J Sport Nutr Exerc Metab.* 2004;14:298-307.

13. Noreen E.E, Buckley J.G, Lewis S.L, Brandaue J, Stuempfle K.J. The effects of an acute dose of Rhodiola rosea on endurance exercise performance. *J Strength* Cond Res. 2013;27(3):839-47.

14. Abidov M, Grachev S, Seifulla R.D, Ziegenfuss T.N. Extract of Rhodiola rosea radix reduces the level of c-reacive protein and creatine kinase in blood. *Bull Exp Biol Med*. 2004;178(7):73-5.

15. Li D, Fu Y, Zhang W, Su G, Liu B, Guo M, Liang D, Liu Z, Zhang X, Cao Y, Zhang N, Yang Z. Salidroside attenuates inflammatory responses by suppressing nuclear factor-kappaB and mitogen activated protein kinases activation in lipopolysaccharide-induced mastitis in mice. *Inflamm Res*. 2013;62:9-15.

16. Chen S.P, Huang L.R, Lu T.M, Wei J.C, Wu T.C, Tsai W.Y, Tsai C.H, Yang C.C. Complementary usage of Rhodiola crenulata (L.) in chronic obstructive pulmonary disease patients: the effects on cytokines and T cells. *Phytother Res*. 2015;29(4):518-25.

17. Spasov A.A, Wikman G.K, Mandrikov V.B, Mironova I.A, Neumoin V.V. A double-blind, placebo-controlled pilot study of the stimulating and adaptogenic effect of Rhodiola rosea SHR-5 extract on on the fatigue of students caused by stress during an examination period with a repeated low-dose regimen. *Phytomedicine*. 2000;7(2):85-9.

18. Olsson E.M, von Schéele B, Panossian A.G. A randomised, double-blind, placebo-controlled, parallel-group study of the standardised extract SHR-5 of the roots of Rhodiola rosea in the treatment of subjects with stress-related fatigue. *Planta med*. 2009;75(2):105-12.

19. Shi L, Wang C, Zhou X, Zhang Y, Liu Y, Ma C. Production of salidroside and tyrosol in cell suspension cultures of Rhodiola Crenulata. *Plant Cell Tissue Organ Cult.* 2013;114:295-303.

20. Panossian A, Wikman G, Sarris J. Rosenroot (Rhodiola rosea): traditional use, chemical composition, pharmacology and clinical efficacy. *Phytomedicine*. 2010;17:481-93.

21. Chiu T.F, Chen L.L.C, Su D.H, Lo H.Y, Chen C.H, Wang S.H, Chen W.L. Rhodiola crenulata extract for prevention of acute mountain sickness: a randomized, double-blind, placebo-controlled, crossover trial. *BMC Complement Altern Med*. 2013;13(1):298.

23. Panossian A, Wagner H. Stimulating effect of adaptogens: an overview with particular reference to their efficacy following single dose administration. *Phytother Res*. 2005;19:819-38.

23. Walker T.B, Robergs R.A. Does Rhodiola rosea possess ergogenic properties? *Int J Sport Nutr Exerc Metab*. 2006;16(3):305-15.

24. Abidov M, Crendal F, Grachev S, Seifulla R.D, Ziegenfuss T.N. Effect of extracts from Rhodiola rosea and Rhodiola crenulata (Crassulaceae) roots on ATP content in mitochondria of skeletal muscles. *Bull Exp Biol Med*. 2003;136(6):585-7.

25. Walker T.B, Altobelli S.A, Caprihan A, Robergs R.A. Failure of Rhodiola rosea to alter skeletal muscle phosphate kinetics in trained men. *Metabolism*. 2007;56(8):1111-7.

26. Shanely R.A, Nieman D.C, Zwetsloot K.A, Knab A.M, Imagita H, Luo B, Davis B, Zubeldia J.M. Evaluation of Rhodiola rosea supplementation on skeletal muscle damage and inflammation in runners following a competitive marathon. *Brain Behav Immun*. 2014;39:204-10.

27. Xin T, Li X, Yao H, Lin Y, Ma X, Cheng R, Song J, Ni L, Fan C, Chen S. Survey of commercial Rhodiola products revealed species diversity and potential safety issues. *Sci Rep*. 2015;5.

28. Li T, He X. Quantitative analysis of salidroside and p-tyrosol in the traditional Tibetan medicine Rhodiola crenulata by Fourier Transform Near-Infrared Spectroscopy. *Chem Pharm Bull*. 2016;64(4):289-96.

29. Chinevere T.D, Cadarette B.S, Goodman D.A, Ely B.R, Cheuvront S.N, Sawka M.N. Efficacy of body ventilation system for reducing strain in warm and hot climates. *Eur J Appl Physiol*. 2008;103(3):307-14.

30. Duncan M.J, Clarke N.D. The effect of acute Rhodiola Rosea ingestion on exercise heart rate, substrate utilisation, mood state, and perceptions of exertion, arousal, and pleasure/displeasure in active men. *J Sports Med*. 2017 Aug 18. 2014:2014: ArticleID 563043: doi:10.1155/2014/563043.

31. Nielsen B, Nybo L. Cerebral changes during exercise in the heat. *Sports Med*. 2003;33(1):1-11.

32. Maughan R, Shirreffs S, Watson P. Exercise, heat, hydration and the brain. *J Am Coll Nutr*. 2007;26(5):S604-12.

33. Nybo L, Nielsen B. Perceived exertion is associated with an altered brain activity during exercise with progressive hyperthermia. *J Appl Physiol*. 2001;91(5):2017-23.